HEALTH AND CONFORT IN XIX CENTURY: THE CASE OF HEATING AND VENTILATION IN BARCELONA

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In the 1860s two studies on heating and ventilation: C*onsideraciones generales acerca de las aplicaciones de ciertos principios científicos a la teoría y construcción de los aparatos de calefacción* by Lucas Echeverria and *Calentamiento y ventilación de edificios* by Francisco de P. Rojas were undertaken in the space of four years. The former paper was delivered to the Royal Academy of Sciences and Arts in Barcelona in March 1864 but was never published whereas the latter was published and awarded a prize by the Royal Academy of Exact, Physical and Natural Sciences in Madrid in 1868. Shortly afterwards, Josep Vallhonesta published in Barcelona his *Nuevo sistema de ventilación para mantener frescos en el verano los edificios públicos y particulares,* a study on ventilation and natural refrigeration. The three studies were undertaken by industrial engineers who were or became teachers at the School of Industrial Engineering of Barcelona. They were also members of the Royal Academy of Sciences and Arts in Barcelona.
The present paper seeks to analyse these works in their context and highlight the innovations introduced by the authors from the practical and theoretical perspectives. The works, which are poorly documented, formed part of the European trend of the time and are notable examples of transfer of knowledge diffused by the École Centrale des Arts et Manufactures of París to other countries.

Heating and ventilation in Spain

In the book *Manual de Física General y Aplicada a la agricultura y a la industria,* which was probably the first book on heating and ventilation in Spain, Eduardo Rodriguez, who trained engineers in the Royal Industrial Institute in Madrid, pointed out the deplorable situation of heating in Spain. He noted that old houses either lacked heating or employed braziers. No public buildings, such as libraries, hospitals, churches or barracks were fitted with a general system of heating. The needs of heating were covered exclusively by the brazier despite the fact that the air could become unbreathable and lethal owing to carbon monoxide (Rodríguez, 1858: 366-367). Eduardo Rodriguez graduated from the École Centrale des Arts et Manufactures in Paris and in 1858 he taught industrial physics in Madrid at a centre that prepared industrial engineers.
Two decades later, the situation had not changed as the engineer Gumersindo Vicuña stated in a review. He pointed out that in Spain only few stoves, chimneys or braziers were located in some rooms to heat a public building or private residence. Few public buildings were heated and private residences used dangerous braziers that could pose a serious health risk. Vicuña attributed this situation to the warm weather in some parts of the country and to the general poverty of the population. Nevertheless, he advocated heating not only for comfort but also for health. These two reasons were, in his opinion, overlooked by architects and doctors, who were not aware of their importance (Vicuña, 1874: 361).
The introduction of scientific ventilation into Spain is closely linked to heating. Ventilation was included in the physics syllabuses of technical schools and like heating it was described in the book of Rodriguez, who was the first engineer to treat this

subject in Spain. He dedicated only 7 pages to ventilation and established a minimum flow of 6 m^3/h per person to renew the air. Rodriguez opted for methods of ventilation based on heat rather than on machines since the latter required maintenance. He devoted few lines to fans powered by a steam engine or operated manually as was the practice in prisons. He concluded that there was a the need for ventilation (Rodríguez, 1858: 335-352).

Twenty years later, Vicuña affirmed that the situation had not improved despite the fact that only three buildings were adequately ventilated in Spain, a country where ventilation was of the paramount importance because of the long hot summers. However, the most common measure consisted in closing theatres in summer, avoiding meetings and cancelling university classes and court hearings (Vicuña, 1874: 362).

Despite this inauspicious state of affairs, some progress was made as demonstrated by the three works of the engineers of the Industrial Engineering School of Barcelona.

Advances in heating came from the north

Heating needs continued to be resolved with braziers in Spain whereas new systems were developed in England and France. Traditional fireplaces were initially refined in the XVIII Century by Nicolas Gauger[1] and Benjamin Franklin[2] and especially by the Count of Rumford. In his *Mémoires sur la chaleur* Rumford described his experiments and his contentious relationship with Bertholet. While Rumford believed that heat was movement, Bertholet with the support of the Institute of France argued that heat was a fluid that passed from one body to another[3]. Besides rejecting the caloric theory, Rumford made fundamental improvements to fireplaces. These improvements consisted in orienting the firewall at angles so that more heat could be radiated into the room. The hot air was forced to circulate above the fireplace, behind and along the sides in order to recover heat (Gallo, 2006a: 37) (Donaldson, 1994: 28) (Garrison, 1927) (Joly 1872) (Figuier, 1867).

However, the changes that occurred in the late XVIII and early XIX century improved the central heating systems in public buildings. These systems consisted in producing heat centrally and in distributing it into the different rooms using a fluid that could be air, water or steam. These systems were specially designed for public buildings such as hospitals or prisons rather than for domestic use. There was a precedent, in the middle of XVIII century, for the design of heating system for the New Palace of Postdam that used hot air. Later we could add a Hospital in Mainz, a cotton factory in Derbyshire and another hospital in Belper at the end of the century. Hot air cockle stoves spread to Europe from Scandinavia and Germany to France (Garrison, 1927: 59), (Donaldson, 1994: 30-35).

Although the use of hot water for heating was inspired by hot springs, it was only applied in the XVIII century to greenhouses such as the one designed in 1716 by Martin Triewald in Newcastle upon Tyne (Donaldson, 1994: 41). Jean Simon Bonnemain used hot water to heat an incubator of chicks in France at the end of the century. But the person who made the most important contribution to the diffusion of the use of hot water for heating was Jean Frederich Marquis de Chabannes, a French nobleman who

[1] *La Mechanique du Feu* of Nicolas Gauger was published in 1713 and was a relevant analytical study on the fireplaces.

[2] Benjamin Franklin (1706-1790) worked on the problem of fires and in 1740 he designed and invented the fireplace Pennsylvania that prevented the flow of smoke descending and providing more efficient heating. Franklin published his Observations on Smokey Chimneys in 1793 and gave rules on the size of the fireplaces, as well as the design of various types.

[3] *Mémoires sur la chaleur, par le Comte de Rumford.* París: Chez Firmin Didot, Libraire, 1804.

lived in England. Chabannes borrowed the idea from Bonnemain and patented it as his own in 1816 (Gallo, 2010: 1117 - 1126) (Gallo, 2006b: 1043-1060) (Gallo, 2006c: 207). The first attempts to use steam for heating occurred at the end of the XVIII century. William Cook in a report delivered to the Royal Society and published in the Philosophical Transactions in 1745 established references for the application of steam for heating. Notwithstanding, the first study on this system was written by Robertson Buchanan in 1807 and was entitled *Essay on the Warming of Buildings by Steam Mills and Others*. Despite the fact that this system was not employed in Great Britain, except in some greenhouses, it was adopted in the USA thanks to the permissive regulations concerning steam engines. Significant advances in steam heating were made in 1880 with the installation of a power plant that supplied steam to a distribution network under the streets of New York to the buildings in the area. This facility was developed by the New York Steam Company and became known as district heating (Donaldson, 1994: 60).

Under the influence of Buchanan (Gallo, 2008: 347-355) Thomas Tredgold in 1824 published, *Principles of Warming and Ventilating Public Buildings, Dwelling Houses, Manufactories, Hospitals, Hot Houses,* which was one of the most influential treatises of the XIX century. The first edition of this work was sold out immediately and the author published a second edition that was translated into French by T. Duverne, which increased its circulation. As regards heating, Tredgold focused on the use of steam as a heat-transfer fluid. He preferred it to other systems because of the ease of diffusion in all directions with little heat loss (Tredgold: 1825, 28).

Tredgold acknowledged that steam was not usually employed for heating private residences but he recommended its use in addition to fireplaces to heat areas such as halls, corridors or stairs. To this end, Tredgold focused on applications for public buildings (churches, classrooms, theatres, hospitals and prisons) and for installations (greenhouses, factories and workshops). For hospitals, he recommended the use of a boiler to convey steam to the top floor from where it was piped to different parts of the building in order to maintain a uniform temperature. Less attention was devoted to prisons, since he considered it unnecessary to heat the cells with the exception of the infirmary. The novelty of his study did not overlook the lack of practical applications. Especially significant are the descriptions and plates at the end of his book that only refer to a chapel, a silk factory and a greenhouse.[4] These places were probably the only ones where steam had been applied successfully (Tredgold, 1825: 425).

Steam was also the system that Reid used to heat the Houses of Parliament in London. David Boswell Reid, professor of physics at Edinburgh, was summoned to London in 1834 to design a system to heat and ventilate the Houses of Parliament that had been destroyed by a fire. The new Houses of Parliament needed a new system and Reid opted for steam. The air was conveyed to the plenum where it was heated by a battery heater (Donaldson, 1994: 68).

However, Reid progressed from steam to hot water. In 1844, his fundamental work: *Illustrations of the theory and practice of ventilation with remarks on warming, lighting exclusive, and the communication of sound* provided valuable insights into the change that had occurred in the first half of the century. This book is indispensable manual of both heating and ventilation techniques. After analysing the different heating systems such as the open fireplace, stove, steam system and hot water devices, Reid opted for

[4] The drawing VII and VIII describe the Portland Chapel in Cheltenham which was heated by a steam boiler built by Bailey in 1821. Also includes the silk factory owned by Shute & Cie and located at Watford and also built by Bailey Holborn in 1817. Finally, the following draw describes a private complex of greenhouses near London also built by Bailey in 1821.

the last system. His experience led him to believe that heating by steam did not work correctly if applied to a room, despite being cheaper to build and despite the fact that the steam could be conveyed naturally long distances. Moreover, in public buildings the steam pipes produced noise and proved less satisfactory than hot water appliances (Reid, 1844: 241).

In his book, an extensive section is dedicated to devices for heating using hot water. In the absence of mechanical systems for pumping water, this fluid was moved by what is known today as thermosyphon, which is based on the fact that the density of water decreases as temperature rises. So hot water rises while cold water descends and a natural circulation is generated. Reid had been directly influenced by the Marquis de Chabannes, borrowing long paragraphs from his essay as well as some pictures. However, while recognizing the merits of this inventor, Reid believed that real progress had been made with boilers and other improvements constructed by Atkinson, Barrow and Turner (Reid, 1844: 242-253).

In 1854, Reid devised a system to heat St. George's Hall, which was located in the centre of Liverpool and was used for the city's civic activities. Reid installed a system similar to that used in the Parliament building, but in St. George's Hall he also introduced hot water to heat the hall (Great Hall), the high court (Law Court) and the concert hall (Concert Room) and other rooms. He combined steam and hot water; the former was used to preheat different rooms before the initiation of activities and the latter was employed to maintain the temperature after turning off the steam (Donaldson, 1994: 69).

Changes in ventilation

Like heating, ventilation has been associated with two human needs: health and comfort. The ancients, despite being unacquainted with the nature and properties of air, understood that fire caused air to circulate since flow was produced by the flame. However, comfort concerned the architects much more than health with the result that balconies, windows and open stairs were incorporated to provide ventilation and to improve comfort. Only tragic events such as death by asphyxiation of miners or of prisoners in confined spaces without ventilation demonstrated that if air was not renewed it could be lethal. Between the XVI and the XVIII centuries, ventilation was only considered under extreme conditions such as in mines. Nevertheless, this period saw considerable improvements in our understanding of the nature and properties of air.[5] In the XVIII century, Nicolas Gauger in his book *Le Mechanique du Feu*, despite having no notion of the composition of the air, described two of its properties: 1) air heats rapidly, 2) hot air rises and cold air descends. Both properties were confirmed by two experiments (Gauger 1714:32-33). In the case of the former property, he used a curved tube, and for the latter he distributed thermometers in a room (Gauger: 1714: 35). This book constitutes a pioneering work that focuses jointly on heating and ventilation. This close link was broken only when mechanical ventilation systems were adopted.

Significant advances in science concerning the composition of air and the changes caused by respiration occurred between the mid XVIII and mid XIX centuries. A tragic event, known as the black hole of Calcutta, focused attention on ventilation. In 1756, a garrison of 146 British and Anglo-Indian soldiers and civilians were imprisoned by the Nawab of Bengal in a very confined space (5 by 6 m), resulting in the death from

[5] Torricelli determined atmospheric pressure; Pascal and Boyle developed the early theory of gases. Even Newton discovered a law of thermal transfer.

suffocation of 123 prisoners. This tragedy contributed to the idea that CO_2 in the air is increased by respiration and combustion, causing the air to be unbreathable.

In the XIX century, industrial development and the growth of urban concentrations led to increased demands for improved heating and ventilation especially in factories. In 1814, the Marquis de Chabannes, developed a combined heating and ventilation system that conveyed air through pipes using a mechanical process. It was in London where Chabannes obtained a patent for a "furnace fan calorífer fumívor". This device was manufactured in London and was employed in various industries, commercial centres and domestic heating and ventilation (Chabannes, 1818) (The Gardener's, 1828: 28-31). He also designed a system of ventilation for the Covent Garden Opera House using ovens and chandeliers to introduce the air and provide a suitable renovation. (Gallo, 2010: 1117-1126), (Donaldson, 1994: 66).

However, in 1824 Thomas Tredgold in his *Principles of Warming*, stressed the importance of ventilation for health reasons, i.e. he sought to determine the degree of air pollution caused by both respiration and perspiration. To ensure safety, he recommended that the air be renewed in 4 cubic feet per minute and per person (6.8 m^3/h). In private residences (Tredgold, 1825: 230-237), Tredgold proposed a mechanism to ventilate a room heated by a fireplace. This mechanism was a siphon shaped tube that prevented the retention of air and the production of smoke (Tredgold, 1825: 343).

If it is said that Tredgold laid the foundations of ventilation, than David Boswell Reid could be credited with its development and consolidation. In his project of the Houses of Parliament, Reid took into account humidification and purification using filters and additives to eliminate foul air. Ventilation was provided by a large chimney with a fire at the base to produce the necessary draught. Subsequently, between 1851 and 1854, ventilation was produced in St. George’s Hall (Liverpool) by a pneumatic machine that renewed and extracted the air and continued to operate for the rest of the century (Donaldson, 1994: 68).

In his book *Illustrations of the theory and practice of ventilation*, Reid in contrast to what had happened previously, contended that ventilation should be taken into account by the architect from the outset and that the cost of the construction and the health of the inhabitants should be considered simultaneously. Both considerations should be complementary (Reid, 1844 : 70-75).

In another chapter, Reid described different ventilation systems. He started with natural ventilation generated by a fireplace where hot air produced a draught that eliminated the fug and replaced it with pure air. He described a fan similar to the one devised by Desaguiliers and also outlined the Archimedes screw designed by Motte in 1834, which sought to replace the fan and the double screw devised by the engineer Combe in Leeds. According to Reid, the best way consisted in using natural ventilation, and in maintaining the movement of the air by heat to increase its extraction. Reid was not opposed to the implementation of mechanical ventilation, but believed that the selection of the device should be done in accordance with local circumstances (Reid, 1844: 100-111).

The work of Reid had positive consequences not only for Europe but also for the USA. After 1842 the techniques described by Reid were widely implemented in hospitals, theatres and other buildings in different countries of Europe, and in the USA. They were displayed in the exhibition halls of the Universal Exhibition of 1867 in Paris. Tredgold and Reid helped to establish the theory of ventilation in the first half of the XIX century before new sources of energy emerged and gave it a new character.

Diffusion of knowledge from the Ecole Centrale de Paris

In the foreword to his book in 1872, Victor Charles Joly deplored the backwardness of France in implementing systems of heating, ventilation and hot water in private residences despite the progress made in public buildings (Joly, 1872: I-IX). Ten years earlier, Arthur Jules Morin had been favourably impressed by the achievements in Britain after his visit to the Universal Exhibition of 1862 in London. Perhaps for this reason his book *Études sur la ventilation* contained a detailed description of the works of Reid in the British Parliament, highlighting the importance of the English author (Morin, 1863: 1-10).

Theories of hygiene emerged during the XIX century following the identification of tuberculosis as a disease and underlining the need for buildings to be made salubrious. In this context, the creation of the École Centrale des Arts et Manufactures led to the training of engineers who played a key role in the development and implementation of centralised systems of heating and ventilation in public buildings, such as hospitals and prisons. After the creation of this school in 1828, professor Eugene Peclet trained a generation of engineers to take into account heating and ventilation for reasons of hygiene as well as comfort.

Jean Claude Eugène Peclet (1793-1857) studied physics at the École Normal and at the Science Faculty in Paris, where he was a pupil of Gay-Lussac and graduated in mathematics and physics. Between 1815 and 1827 he was professor of physics at the Royal College in Marseilles. In 1828 he was appointed *maître de conference* at the Ecole Normal Superieur. Peclet was one of the founders of the Ecole Centrale des Arts et Manufactures, where he taught general physics and industrial physics. He wrote a number of books including the *Traité de la chaleur.* Peclet was considerably influenced by Reid and Gay-Lussac as is shown by his analysis of the ventilation of the Paris Stock Exchange. In his book, Péclet offered some recommendations for heating and ventilation to improve health (Péclet, 1878, III,295). There were two institutions, prisons and hospitals, where health needs were considered to be of paramount importance. Péclet alludes to the ethical conflict concerning the health of prison inmates. Some believed that prisoners did not merit conditions that were healthier than those undergone by honest workers. Péclet advocated the ventilation of prisons using powerful fans that were driven by the prison inmates (Péclet, 1878: III, 427).

A commission was established in 1843 to evaluate the heating and ventilation projects for the Prison of Mazas (in Paris). They selected the project presented by Philippe Grouvelle, which consisted in warming air using hot water pipes. Heat was produced in steam generators located in basements and was then transferred to water containers placed on each floor. Ventilation was achieved by the draught of a chimney (4 m^2 and 29 m high) placed at the centre of the building. The air was removed from each cell by the pipes used for the depositions of the inmates.

The need for hospital ventilation seemed self-evident. Péclet acknowledged that France was lagging behind England, in which country this problem had been studied in the early XIX century whereas in France hospitals were not ventilated until 1840 (if we do not count opening windows). Although Architects did not regard ventilation as a priority, it was well known that specific diseases in hospitals were attributed to the lack of ventilation. Péclet made a distinction between large and small hospitals. In large hospitals, he recommended ventilation by injecting air with a mechanical process that was more advantageous if a steam boiler existed. In small hospitals, metal or cast iron stoves were adequate for heating, and for ventilation he suggested a fireplace with a chimney to remove the hot air (Péclet, 1878: III, 432).

Heating and ventilation in the École Centrale formed part of the subject of industrial physics, which Peclet taught until his death in 1857. Léonce Thomas succeeded Peclet, and was in turn succeeded by Louis Ser and Jules Grouvelle towards the end of the century. Only by knowing who these teachers were can we establish the links between education and business, e. g. the company of Philippe Grouvelle, who together with his son Jules, set up a system for improvement, regulation and construction of boilers; Louis Ser who, in addition to being a teacher, was an engineer of the municipal health service in Paris, which involved the supervision of some hospitals. Another former student of the École Centrale was Emile Trélat, who worked as an architect for the Seine Department and who evaluated the heating of the Nanterre prison and later the Sorbonne prison (Gallo, 2004: 199-201).

A contemporary of Péclet, Artur Jules Morin (1795-1880), challenged the work of his colleague. Before completing his studies in the École Polytechnique, Morin had embarked upon a military carrier, reaching the rank of general. After leaving the army, he was appointed professor of mechanics at the Conservatoire des Arts et Métiers, of which he became director. In his book *Études sur la ventilation,* Morin incorporated several important innovations such as the volume of air needed for renovation, values of which were ten times higher than those proposed by Tredgold and Reid (O'Connors, 2008).

The ideas of the teachers of the Ecole Centrale had spread not only to other schools in the country, especially the Ecole de Travaux Publics where George Espitallier author of *Cours raisonné et détaillé du Bâtiment- Chauffage et ventilation* taught, but also beyond the borders of France. Thus the manuals published by the teachers of the Ecole Centrale exerted an influence on Hermann Rietschel from the Technischen Hochschule in Berlin and also on M Hottinger at the ETH Zürich (Eidgenössische Technische Hochschule), in Zurich (Gallo, 2008: 347-355). And as will be shown in this paper, the influence of the École Centrale and of the Conservatoire subsequently had reached the teachers of the School of Industrial Engineering of Barcelona. Thus, knowledge of heating and ventilation entered Spain initially by direct training at the École Centrale de Paris. This was the case of Eduardo Rodriguez, whom we have already mentioned. But the subsequent introduction and application of knowledge were achieved through the study of texts written by the teachers of the aforementioned centres in Paris.

The works analysed in the present study are a fine example of this French influence. Chronologically, the first to appear was C*onsideraciones generales acerca de las aplicaciones de ciertos principios científicos a la teoría y construcción de los aparatos de calefacción,* which was delivered as a lecture by Lucas Echeverria to the Royal Academy of Sciences and Arts of Barcelona. Four years later, Francisco de P. Rojas, a colleague of Echevarria at the Industrial Engineering School of Barcelona, was awarded a prize for his work *Calentamiento y ventilación de edificios* by the Royal Academy of Sciences of Madrid. After another four years, the engineer Josep Vallhonesta published *Nuevo sistema de ventilación para mantener frescos en el verano los edificios públicos y particulares* in Barcelona.

Lucas Echeverria, engineer and academician

In addition to preparing special commissions and reports, the Royal Academy of Sciences and Arts held meetings in which academicians regularly delivered lectures on some aspects of their scientific activity. These sessions were complemented by others in which the members read summaries of relevant papers in scientific journals from abroad (Barca, 2010: 9). On 10 March 1864, Lucas Echeverria was chosen to deliver a lecture entitled C*onsideraciones generales acerca de las aplicaciones de ciertos principios científicos a la teoría y construcción de los aparatos de calefacción*.

Lucas Echeverria Ugarte was born in Vitoria in 1831 and gained his baccalaureat in 1849 from the Institute of Vitoria, where he served as assistant to the professor of physics. He obtained his degree in Sciences from the University of Madrid in 1854 (Anduaga, 2008). In March of the same year he was appointed assistant lecturer in chemistry at the Industrial School of Bergara (Caballer: 2001: 111). Two years later, he was appointed professor of general and applied physics without remuneration, and he occupied the chair the following year. On account of the closure of the Industrial School of Bergara, he was transferred in September 1860 to the School of Industrial Engineering of Barcelona, where he became professor of industrial mechanics. He combined these classes with others on rational mechanics at the University of Barcelona between 1860 and 1866. While he was teaching engineering he gained his degree in engineering from the School of Engineering of Barcelona in 1864. He obtained his doctorate in 1869 with a thesis entitled *Teoría general del movimiento de las máquinas* at the University of Barcelona. Echeverria was appointed director of the Industrial Engineering School of Barcelona on 23 August 1891. However, his appointment was short-lived as he died suddenly after eleven days (Diario: 1891: 10.379).

Apart from his work as professor, Lucas Echeverría was a member of the Catalan Agricultural Institute of San Isidro (IACS) and of the Barcelona Society of Friends of the Country and was president of the Association of Industrial Engineering of Barcelona and of the Royal Academy of Sciences and Arts (RACAB) between 1868 and1869. In this Academy he held many other posts such as secretary (1863, 1867) and director (1880, 1886, 1890) of the section of physics and chemistry, librarian (1866), and vice-president (1866). On his admission to the Royal Academy in 1862 he delivered a paper entitled: *Sobre el fluido eléctrico*. In this institution, he read other papers including one entitled *Sobre la Termodinàmica* (1874) and delivered a lecture on the *Influencia de los progresos de la Mecánica en la Agricultura* (1884). He also read some summaries of papers that appeared in foreign journals (1866). Echeverria also published an article in the *Revista del Instituto Agrícola Catalán de San Isidro* (1867) and in the *Revista Tecnológico Industrial* (Nòmina, 1913-14, 62-66) and chaired the Association of Industrial Engineers during 1880-1881.

The Echeverría paper C*onsideraciones generales…*

In *Consideraciones generales*… Echeverría sought to demonstrate that an understanding of some theories of physics, chemistry and mechanics played a crucial role in achieving more efficient heating appliances, which would contribute to improving the design of these devices. According to Echeverría the key element in a good design was fuel, the characteristics of which were essential for achieving a good result. Chemical theories allowed him to explain how combustion took place, determine the calorific value of the fuel and to analyse the transmission of heat by convection or radiation.

First, he described the process of combustion, the need for oxygen and the air flow that was generated. This led him to believe that it was necessary to avoid poor combustion in fireplaces so that the circulation of hot air could be facilitated. After this preliminary approach, Echeverria made use of various examples in Volume I of *Traité de la chaleur* by Eugene Péclet, whom he followed closely. Thus, like the French author, Echeverria enumerated certain conditions that he considered essential to constitute a good fuel: 1) it should generate sufficient heat to ensure uninterrupted combustion, 2) it should be abundant to keep costs low, and 3) it should not produce harmful effects. In the same order as Péclet, Echevarría considered the best fuel to be wood, charcoal, peat, coal and coke. All these fuels were composed of carbon and hydrogen which make them more effective (Peclet, 1843: I, 48).

If combustion was explained by chemical theories, the calorific value of the fuel or the number of calories per kilogram generated should be determined by physical methods. According to Echeverria this could be accomplished in two ways. One way involved experiments and the other entailed the use of the calorific value of its components (carbon and hydrogen). Echeverría summarized the text of Peclet on the historical evolution of the determination of these values. He started with the Rumford calorimeter, and followed this up with the Lavoisier and Laplace calorimeters. However, whereas Peclet described these devices and included some numerical examples, Echeverria only made a reference to them. He continued in the same chronological order as the French author, pausing to comment upon the improvements made by Cesar Despretz (1791-1863) in Belgium and Pierre Louis Dulong (1785-1838) in France, using a calorimeter similar to that of Rumford (Peclet, 1843: I, 48). Echeverria made no reference to the research carried out by Marcus Bull in America in 1826, which was also described by Peclet.

Nevertheless, Echeverria provided more information than Peclet about a process to calculate the calorific value. Special attention was given not only to the composition of the fuel but also to the calorific values of its components: For one kilo of fuel, he multiplied the weight of carbon by its calorific value and that of hydrogen by its calorific value and added these two products.

Although Echeverria did not go into the same detail as Peclet did in his book, it may be assumed that he was well acquainted with his subject since we know today of the existence of a Rumford calorimeter in the Industrial School at Bergara (Anduaga, 2008) and of the existence of a copy of the *Traité élémentaire de physique* by Despretz in the library of the Industrial Engineering Scholl of Barcelona.[6] The type of session of the Academy probably obliged Echeverría to simplify his paper in order to make his speech more comprehensible.

Subsequently, Echeverria gave an account of the two forms of transmission of heat during combustion. He analysed the radiant power of fuels and the volume of air necessary to complete combustion in order to obtain a formula to calculate the volumetric flow rate of the air.

To measure the radiant power or quantity of heat emitted in all directions from a body during combustion, Echeverria recommended the use of the Peclet calorimeter and the multiplication of the numerical results using a coefficient. Although Echeverria's determination is imprecise, a good description is provided by Peclet, who described some experiments and devices to determine this coefficient (Peclet, 1843: I, 52).

In order to obtain the amount of air required for combustion and to determine the amount of mixed air and smoke leaving a chimney, it was necessary for Echeverria to resort to chemical theories. It was therefore essential to determine the chemical composition of smoke in CO_2, water and air as well as the elements in 1kg of fuel.

Using the composition of CO_2, he obtained the volume of oxygen per kg of carbon and once the composition of the air was known, he calculated the volume of the air needed to contain this oxygen. According to Echeverría, this theoretical method did not concord with practice because not all oxygen in the air combines with carbon and hydrogen.

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[6] In the Ancien Archive of the Industrial Engineering Scholl of Barcelona, as well as the *Traité de la Chaleur* de Peclet there is a copy of the first edition of DESPRETZ, C (1825) *Traité élémentaire de physique*. Paris: Méquignon-Marvis, which was later, translated into Spanish by Francisco Alvarez in 1844.

To determine the volume of gases produced by combustion, Echeverría recommended the formula that was similar to the one used for thermal expansion.

$$V_T = V(1 + a \cdot t)$$

After highlighting the role of physics and chemistry in the design of heating appliances, Echeverría stressed the importance of mechanics, in particular hydrostatics and hydrodynamics. He presented the case of the determination of the velocity of air that passed through a vertical cylinder. This case was also discussed by Peclet in chapter IV of his book (Peclet, 1843: I, 141). Summarizing this chapter, Echeverría determined the velocity of natural circulation caused by temperature change in flues as in chimneys. Like Peclet, he considered that air behaved like a liquid with the same density as the air and he therefore applied the same formula that was used for falling bodies. Echeverría did not go into as much detail as Peclet, who made some corrections in the formula. This was understandable because Peclet realized that the error was negligible.

In accordance with Peclet, Echeverría insisted that the corrections should take into account the friction of the air against the walls of the cylinder and mentioned the works of D'Aubuisson and Girard on the behaviour of hot air and the correction coefficient that was necessary. Unlike Peclet, who also described several experiments with fireplaces of different materials and using different conditions, he did not take into account these parameters. Nevertheless, Echeverría probably knew the works of D'Aubuisson since the latter author's book *Traité élémentaire de physique*[7] is in the library of the ETSEIB and it is likely that it was consulted by Echeverría before writing his paper.

In conclusion, Echeverría insisted that the theories of chemistry, physics and mechanics should be essential for the construction of chimneys, fireplaces, boilers, dryers and other appliances that require heat. His paper marked the advent of new ideas about heating. It also initiated the process of assimilation of these applications by the professors of the Industrial Engineering School of Barcelona.

Francisco de Rojas pioneer in thermodynamics and electricity.

Francisco de Paula Rojas y Caballero Infante (1834-1909) was born in Jerez de la Frontera and studied at the Royal Industrial Institute of Madrid. He served as assistant at this centre in 1853 although it is not know in which discipline. In 1854 he was appointed supply teacher in the Department of Chemistry at the Industrial School of Seville. Subsequently in 1856, he became professor of general and applied physics at the Industrial School of Valencia. However, as a result of the political and economic crisis of 1865 in Spain, which led to the closure of all engineering schools with the exception of the one in Barcelona, Rojas was assigned to the Engineering School of Barcelona to teach machine construction. Nevertheless, Rojas continued to be interested in industrial physics which he was finally able to teach in Barcelona from 1880 (Pohl, 2006: 97). Two years later, he moved to the newly created Escuela General Preparatoria in Madrid, where he was appointed professor of hydrostatic, hydrodynamic and general hydraulics (Lusa, 1999:19).

During his stay in Barcelona, Rojas focused his attention on heating and thermodynamics from both the theoretical and practical points of view. He published a book entitled *Calentamiento y ventilación de edificios*, for which he received an award from the Real Academia de Ciencias Exactas, Físicas y Naturales de Madrid in 1867. He obtained recognition for his work on *Thermodynamics* from the Ateneu of Barcelona

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[7] Is a third edition of the book: D'AUBUISSON DE VOISINS, George François (184?) *Traité d'hydraulique à l'usage des ingénieurs.* París : Pitois-Levrault.

in 1876. These two works enabled him to gain admission to the scientific institutions in Madrid and Barcelona.
Rojas was considered to be the foremost specialist in heating and ventilation of his time. For Josep Serra Bonastre, who had attended his classes as a student, Rojas was not only a pioneer in the introduction of heating applications but also of electricity, which formed part of the syllabus of industrial physics until 1901 (Serrat, 1909: 160,161).
He was elected member of the Royal Academy of Sciences and Arts of Barcelona in 1873, but it was not until 1877 that he delivered his inaugural lecture (one year after receiving the award from the Ateneu) entitled: The physical problem and the chemical problem were resolved by the mechanical one (*El problema físico y el problema químico se resolvieron en el mecánico*). Henceforth, he took an active part in the affairs of this institution. In 1878 he delivered a paper: Concerning the way to measure pressures of liquids produced by gravity (*Sobre el modo de medir las presiones de los líquidos originados por la gravedad*). In 1881, he wrote another paper entitled: Determination of voluntary movement in our body (*Determinación de los movimientos voluntarios en nuestro organismo*). And in 1884, he read a paper: Considerations and calculations of incandescent lamps (*Consideraciones y cálculos de las lámparas incandescentes*).
Rojas became director of the section of physical and chemical sciences at the Royal Academy of Sciences and Arts of Barcelona and participated in several commissions such as the one to study electric light divisibility in 1880. Even though he was not resident in Barcelona, he continued to collaborate with this institution giving advice on some reports of physical devices (Nòmina, 1914-1915).

***Calentamiento y ventilación de edificios* by Rojas.**
According to the author, this book, published by the Royal Academy of Exact Sciences of Madrid, not only constituted a new approach to heating and ventilation systems but also challenged the works of French scientists such as Eugene Péclet and Artur Morin: *Traité de la Chaleur* and *Etudes sur la ventilation.*
Calentamiento y ventilación de edificios contains 262 pages with 16 plates and is divided into six chapters. The first chapter concerns the theory of ventilation and the second one deals with what today is known as the calculation of thermal loads, but which Rojas termed the determination of the power of the devices. The third chapter considers the heating of buildings and challenges the use of braziers, calling for their prohibition because of the risk of monoxide poisoning. Fortunately, he said, doors and windows never close properly in Spain.
The fourth, fifth and sixth chapters consist of comparative studies of a number of systems. The fourth chapter deals with ventilation and the fifth and sixth concern heating with respect to the cost and the fuel used. Rojas focused on different systems of heating and ventilation in a hypothetical military hospital to be located in Barcelona or Valencia. This hospital would cater for 144 patients who would be distributed over six rooms on three floors. The reason for choosing a hospital was that this type of building required a regular supply of heating and ventilation. For heating, he made use of three systems: 1) heating by air with calorifers inside or outside, 2) heating by steam or steam combined with water, and 3) heating by circulation of hot water.
As for the ventilation, Rojas uses four systems: 1) chimney by suction from below, 2) chimney by suction from above, 3) suction from each floor, and 4) the mechanical system. The combination of these systems of heating and ventilation provided him with seven options.

Num.	Uses	Systems
First	Heating	Indoor calorifers of hot air
	Ventilation	Chimney by suction from below
Second	Heating	Outdoor calorifers of hot air
	Ventilation	Chimney by suction from below
Third	Heating	Outdoor calorifers of hot water
	Ventilation	Chimney by suction from below
Fourth	Heating	Outdoor calorifers of steam
	Ventilation	Chimney by suction from below
Fifth	Heating	Pipes or stoves heated only by steam or by water heated by steam, placed in the rooms to be heated
	Ventilation	Mechanical ventilation
Sixth (Duvoir-Leblanc system)	Heating	Circulation of hot water in pipes or stoves placed in the rooms to be heated
	Ventilation	Chimney by suction from above
Seventh (Hamelincourt system)	Heating	Circulation of hot water in pipes placed inside the walls
	Ventilation	Suction from each floor

The last chapter, which is dedicated to heating systems applied to buildings such as barracks, hospitals, churches, schools and theatres, constitutes the conclusion of his study.

The first system of heating consisted in installing a calorifer on each floor. The calorifer was composed of two concentric cylinders. Combustion was produced inside the internal cylinder using air from the room. Smoke was extracted through a chimney in the wall. The clean air, which was warmed with no contact with the air and the smoke produced by the combustion, circulated in the area between the two cylinders. Once warmed, the air was conveyed by ducts on the roof or through the space between the floor and the ceiling known as the plenum.

Rojas employed the same calorifer as the one that Péclet had installed in primary schools in France. The description of this calorifer is found in volumes II and III of *Traité de la Chaleur*. In volume II, Péclet described this calorifer among others and in volume III, he explained their applications in primary schools (Péclet, 1860: II, 338). During an inspection, he was distressed by the unhealthy conditions of the primary school annexes to the Écoles Normales (teacher training colleges) in France and demanded the intervention of the Minister of education. As a result, Péclet was charged with the task of drafting guidelines on heating and ventilation in primary schools, which he reproduced in volume III of his Traité (Péclet, 1878: III, 533). This calorifer, which was not cylindrical but prismatic, was installed in three schools in Paris and was a benchmark for applications in other countries.

Nevertheless, Rojas observed that the fireplace of Péclet's calorifer was small and only removed air by suction. This was a drawback for ventilating hospitals in summer. Schools, however were not affected as they were closed for the summer holidays. Consequently Rojas made some changes to Peclet's calorifer: 1) he increased the annular space between the cylinders and 2) he distributed the warmed air over three places in the room instead of one to maximize uniformity. These changes resulted in a calorifer that was more economical albeit less aesthetic (Rojas, 1868: 486).

The second system involved outdoor calorifers that distributed warm air to different rooms by ducts. To warm the air Rojas chose a simple calorifer such as the one described by Peclet i.e. a brick chamber containing a fireplace with iron pipes through which air and smoke were conveyed to exchange heat (Péclet, 1860: II, 345). Additionally, Rojas included a drawing of a cross section of his calorifer.

The fireplace was covered by a cast iron dome connected to a concentric pipe through which smoke was extracted and heat transferred from the smoke to clean air (Rojas, 1868: 489). This calorifer was placed in the basement and the warm air was conveyed by a duct to heat the different rooms. Additional ducts were used to extract the stale air and these were connected to a large chimney in the centre of the courtyard of the building.

The third system involved outdoor calorifers of hot water placed in the basement. Each calorifer contained six series of ten upright cast iron pipes linked to curved pipes. These pipes were connected above by a horizontal pipe and below to the boiler situated in the middle of the basement. Water circulated because of the variation in density i.e. hot water rises and cold water descends. The calorifers heated the basement air that was conveyed by ducts to the different rooms. On each floor, heated air was introduced through the plaster cornices that were perforated by a number of outlets distributed along its entire length. The stale air and the smoke were extracted to a large chimney located in the middle of the yard. One of the advantages of this system, for Rojas, was that rooms would be free of obstacles and the cornices could be used as a decoration (Rojas, 1868: 494).

The fourth system that used outdoor steam calorifers was identical to the third one except that the boiler produced steam instead of water. In this case, Rojas recommended that the pipes should be insulated.

These four heating systems used the same type of ventilation consisting of a chimney of suction from below. This type of suction involved the installation of a fireplace at the bottom of the chimney so that vitiated air could be discharged by the heat. The suction was usually achieved by locating, in the middle of the yard, a large chimney that extracted stale air (Rojas, 1868: 486).

The fifth system, which consisted of pipes and steam stoves[8] placed inside the rooms, was the same as the one installed in the men's wing of the Lariboisière Hospital in París. This hospital in the North of París was built by the architect Martin Pierre Gauthier (1790-1855) and was inaugurated in 1846. Its heating and ventilation system constituted a benchmark in the debate over comfort and health in France at that time.

The General Council of Hospitals in France initially planned to adopt the Duvoir-Leblanc system of heating which had been used in hospitals successfully. But the Council decided to hold a public tender, which was won by Phillipe Grouvelle, Léonce Thomas, Camile Laurens and Joseph Farcot (all of whom were *centraliens* except Grouvelle). Not wholly convinced, the Council sought advice from Artur Morin, who was the director of the Conservatoire des Arts et Metiers. Morin recommended that the hospital should be divided into two parts: The men's wing on the right was to be equipped with the Grouvelle system and the women's wing on the left, with the Duvoir-Leblanc system. This decision transformed the hospital into a kind of experimental laboratory that generated a passionate debate over the most suitable system for heating and ventilating hospitals. The engineers and the physicians gave their support to one of the two systems (Gallo, 2004: 199-201) (Gallo, 2003).

The men's wing was heated by steam produced outside and piped into the building where it was transferred to hot water stoves (steam stoves could also be used) to heat the room. Ventilation was produced by a fan driven by a steam engine. In Rojas's description, the fan drove in clean air from the outside through a duct that crossed

[8] Or by stoves of water heated by steam

longitudinally the ceiling of each floor. This duct had openings where the stoves were placed. The stale air was extracted by evacuation ducts located inside the outer walls and was conveyed to the roof where it was removed by suction using a fireplace (Rojas, 1868: 555).
Morin in volume I of *Etudes sur la ventilation* stated that despite raising the pressure of the boiler, steam stoves attained so little pressure that the risk of an accident was negligible. By contrast, in the morning when the heating was reduced some noise could be heard owing to the condensation, which constituted a risk of an explosion (Morin, 1863: 356). Air was taken directly from the basement in Rojas's description, whereas in the case of Lariboisiere Hospital it was taken from a duct located on the corner of the chapel tower.
A number of studies were carried out by the chemist C. Grassi, and the engineers Émile Trélat and Henry Peligot to determine whether the air came from the tower or from elsewhere. To this end, the Seine Prefecture set up a commission which involved the collaboration of the engineers Félix Leblanc and Louis Ser. All these experiments showed that between 25 and 35% of the air proceeded from the tower and the rest came from other openings such as open doors. For this reason, the construction of a duct was considered to be to expensive and was therefore not recommended. Instead of a duct, air could be taken from each floor or from under the floor, as suggested by Rojas (Morin, 1863: 365).
The sixth system takes its name from its inventor León Duvoir-Léblanc and used stoves of hot water. It consisted of a hot water boiler and a large stove located at the top of the building. The function of this stove was threefold: 1) it absorbed water expansion, 2) it distributed water to the different rooms, and 3) it warmed stale air. A pipe conveyed hot water from the boiler into the large stove through the chimney. Water, after being warmed by smoke, was piped into the different stoves placed in each room in order to transfer heat to air before returning to the boiler. The large stove described by Rojas was fairly similar to the stoves employed in the fifth system but with the difference that the water did not attain a temperature of 100ºC. The clean air was conveyed to the patio through six ducts that were placed in such away that the air went through the stoves. Stale air was extracted via the lower part of the wall through an evacuation duct that led to a general chimney in the loft producing suction from above.
The description of Rojas was very similar to that of the installation of the women's wing of the Laribiosière Hospital except for the number of stoves placed inside the room (four instead of three).
One of the disadvantages of the Duvoir-Leblanc system, detected by Péclet, was the dependence of ventilation on heating which was more effective in winter then in summer. For this reason, Péclet, who advocated mechanical ventilation, recommended that ventilation should be independent of heating (Péclet, 1878: III, 455). Rojas considered these measures to be excessive given the improvements. Morin, however, defended this system with respect to the men's wing. Nevertheless, experiments made by Grassi, Trélat and Perigot demonstrated that it was possible to eliminate stale air even in summer. But windows were to be kept open to increase air flow (Morin, 1863: 457).
The controversy surrounding the merits of the two systems divided the engineers, architects and physicians. Some scholars such as the architect Gaultier de Chabry or the physician Jean Christian Boudin like Morin favoured the Duvoir-Leblanc system. However, Trélat defended the equivalence of the two systems in the case of heating but opted for the men's wing in the case of ventilation. By contrast Morin considered that the women's wing was better ventilated because it smelled better (Gallo, 2003). Rojas

was drawn to the simplicity of the Duvoir-Leblanc system as regards ventilation since there was no need for a steam engine but realized that this advantage would be offset by higher costs in summer (Rojas, 1868: 554).

The seventh system, which was named after M. Hamelicourt, a former student of the École Centrale, produced heat by circulating hot water through pipes located inside walls. The system involved heating water in a boiler located in the basement, whose combustion products were eliminated by a chimney in the middle of a courtyard. The boiler was connected to an expansion tank placed by Rojas in the attic to absorb water expansion. The hot water was piped from the boiler and ascended through ducts placed inside the wall. Water warm the air that circulated through the ducts. Stale air was extracted through ducts on each floor and as it ascended its temperature increased. These ducts played the role of chimneys, removing air by suction from each floor (Rojas, 1868: 515-519).

In his *Etudes sur la ventilation,* Morin also described the Hamelicourt system and drew attention to the fact that the temperature of the water reached nearly 100ºC, resulting in a good circulation and in a uniform transfer of heat. This system obviated the need for a stove (Morin, 1863: III, 76). In addition to the uniform heating, one important advantage was that the heat of the water was maintained for some time despite the fact that the boiler was turned off. This constituted an important advantage over a system that depended on the use of many pipes. Nevertheless, of the heating systems that used hot water, Morin opted for the Hamelincourt system given the advantages of pipes and vertical ducts over stoves (Morin, 1863: III, 80-81). Rojas, however, believed that the simplicity of the Hamelincourt system was a liability in the case of breakdowns and leaks (Rojas, 1868: 553).

In chapter VI, Rojas compared the systems from the technical and economic points of view. He concluded that, if only heating without ventilations was considered, the most economical system for a hospital was the system that used indoor calorifers. In second place, was the system that employed outdoor calorifers. In third place, the system that used hot water. And finally, the most expensive was the one that used steam.

He also compared the first three ventilation systems from the technical point of view. Thereafter, he compared them with the fourth system from the economical point of view. The chimney by suction from below was the most suitable system since its fuel consumption was the lowest. Mechanical ventilation was less economical, additional costs would include the boiler, chimney, installation and maintenance (Rojas, 1868: 551-553). When considering heating and ventilation together, the most economical system was the one that used steam for heating combined with mechanical ventilation such as the one installed in the men’s wing at Lariboisiere Hospital in Paris.

Rojas concluded his study with some recommendations for heating buildings such as barracks, hospitals, churches, primary schools and theatres. He believed that a close collaboration between the architect and the engineer was indispensable in the course of the constructions of the buildings.

The work of Rojas on heating and ventilation marked another important step in the introduction of improved techniques in engineering training in Barcelona. But neither Rojas nor Echeverria considered the need for fresh air. It was another engineer from Barcelona, Josep Vallhonesta, who devoted his attention to this subject at a time when refrigeration techniques were just in their infancy and were exclusively applied to ice production.

Josep Vallhonesta pioneer of colour chemistry.

Josep Vallhonesta Vendrell (1835-1899) was born in Barcelona and qualified as an engineer at the Royal Industrial Institute of Madrid in 1856 in the same year as Rojas. Thereafter, he obtained a grant to study textile dyeing and printing in Paris with Eugène Chevreul at the Gobelins Factory in 1860. After completing his studies, Vallhonesta worked at the Gobelins laboratory in París for four years during which he received a visit from his colleague Ramon de Manjarrés, who stopped in Paris on his way to the Universal Exhibition of 1862 in London (Barca, 1995: 387). Vallhonesta also worked at the silk dye works of O. Briffaud Successeurs and also at the wool dye works of Jean Bechars et Fils in París. On his return to Barcelona, he prepared a report on the colour system invented by Chevreul with the aim of introducing it into the chromatic circle at the dye works in Barcelona (Duran, 2004: 58).

Subsequently, he became director of several industrial plants in Catalonia. For example in 1875 he supervised the dyeing department of the Sert Germans & Solà factory. He was also vicedirector of the Telegraph Company, where he prepared a report on the telegraph line between Spain and Portugal from Tui to Valença do Minho.

Vallhonesta combined his work as an engineer with his teaching. During 1873-1874 he was assistant professor of inorganic and organic chemistry at the University of Barcelona. In 1888 he taught dyeing at the School of Arts and Crafts, which was affiliated to the Industrial Engineering School of Barcelona. And finally in 1891, he took over from Ramon de Manjarrés (who moved to the University of Seville) as professor of inorganic chemistry at the Industrial Engineering School of Barcelona.

Vallhonesta was elected to the Royal Academy of Sciences and Arts in 1870. In this institution, he occupied several positions as secretary (1880) and librarian (1890, 1892). He delivered a lecture entitled: The importance of aniline colours in the dyeing industry (*Importancia de los colores de la anilina en la industria de la tintura*) in 1870; another, on the use of gas obtained from the distillation of wood (*Aprovechamiento de los gases que resultan de la destilación de la leña*) in 1873; and two others lectures related to colours applied to fabrics entitled: 1) Comparison of dyeing processes with ancient and modern dyestuffs (*Comparación entre los procedimientos de tintura con las materias colorantes antiguas y modernas;* 1881). 2) On the laws governing the successive contrast of colours (*Sobre las leyes que rigen el contraste sucesivo de los colores*; 1887) (Nòmina 1914-15: 55-60).

Vallhonesta also chaired the Association of Industrial Engineering of Barcelona in 1879 at a time when industrial engineers played a major role in the industrial development of Barcelona (Revista, 1880, 11). An obituary of Vallhonesta was published in the newspaper[9] in 1899.

Ventilation for cooling buildings

In 1872, Vallhonesta published a book entitled: *Nuevo sistema de ventilación para mantener frescos en el verano los edificios públicos y particulares* (New system of ventilation to maintain public buildings and private residences cool in summer) in which he combined ventilation and cooling. Some studies on ventilation and heating had been written by prestigious technicians (Vallhonesta was probably thinking of Rojas) but only a few public buildings were equipped with incomplete and costly systems. Vallhonesta considered that more emphasis should be placed on cooling than on heating in Barcelona given its balmy Mediterranean climate. Thus, he proposed a new approach that combined ventilation and cooling, i. e. a system that required no

[9] La Vanguardia, 25 January of 1899, 1.

capital for installation or maintenance. The only condition was to take into account ventilation and cooling when designing the building.

In the absence of developed systems of refrigeration, Vallhonesta took advantage of the studies on ventilation and heating. Before providing a description of his system, he focused on the requirements of the air before being introduced into a room. He drew on the experience of other scientists, such as Morin and Peclet. Vallhonesta considered a minimum volume of 5 or 6 m^3/h of ventilation in normal conditions. He recommended an increase in these values up to 10, 15 to 20 m^3/h if the amount of stale air was excessive as in the case of the Mazas prison in France (Vallhonesta, 1872: 9). All these data were obtained from the *Traité de la Chaleur* by Peclet (Peclet, 1878, III, 397).

According to Vallhonesta, the correct volume of air depended on 1) the use of the building, 2) the number of inhabitants, and 3) the frequency and duration of meetings. He believed that the air to be introduced should be neither too warm nor too cold but a temperature slightly below that of the room (Vallhonesta, 1872: 13).

After analysing the conditions of the air, Vallhonesta set about finding new ways of natural ventilation. Given that warm air rises and cold air descends, ventilation could be obtained by making use of the sun's radiation to heat metal ducts (Vallhonesta, 1872: 14).

He opted for the Saussure box, which consisted of a black wooden box covered with two sheets of glass to warm the air and assist its circulation. The device proposed by Vallhonesta was very similar to what we would today call solar panel, which heats air using the greenhouse effect. The disadvantage of this system was that it supplied ventilation but not cooling. Given that not all sides of the building were subjected to the same conditions, he considered the possibility of obtaining cool air from the north face which did not receive direct sunlight. However, heat and humidity is sometimes so oppressive in summer that this system did not work and cool air would have to be obtained from elsewhere. All these considerations led Vallhonesta to come up with a proposal that consisted of having a garden with plants and trees behind the house from which clean and cool air could be obtained.

As regards cooling, Vallhonesta was aware that if a hole is made in the ground at a given depth, the temperature is unaffected by climatic conditions. Thus, he proposed the construction of an underground duct to circulate clean air before its introduction into a room.

One difficulty, anticipated by Vallhonesta, was that outside air that passed through the duct would be warmed until it attained the outside temperature. He therefore modified the dimensions of the duct. He also proposed the introduction of fresh air during the night for use the following day. If the problem arose in the afternoon, the walls of the duct would be sprayed with water to obtain moisture to cool the air by vaporisation (Vallhonesta, 1872: 20).

This system of cooling only works when doors and windows are closed. Otherwise, outside air enters and interrupts the cooling process. The walls should be sufficiently thick and should be made of a suitable refractory material and the balconies and windows should be equipped with curtains. If the rooms were large there would be ducts for the incoming air and for the evacuation of stale air (Vallhonesta, 1872: 24).

Vallhonesta designed a building that had a north facing garden with large trees and bushes and plants with thick foliage. The air would be drawn from these plants via ducts. This air would be kept cool and purified provided that the garden was watered regularly. The system would be feasible only if the differences in temperature between the sun and the shade were sufficiently large. Fresh air would be conveyed by ducts

installed underground at a depth where the temperature was unaffected by the weather and would then be introduced into a room through other ducts located inside the walls.
After use, the air would be conveyed through flat ducts on the roof, similar to the Saussure box, part of which was made of zinc, painted in black and covered with glass to be heated by the sun. The warm air was conveyed into a metallic chimney in the middle of the roof.
The doors and windows had to be kept tightly closed to prevent the warm air from entering and interrupting the cooling process. The outside walls would have to be made of a refractory material of a suitable thickness. In fact, Vallhonesta's method was not only a precursor of solar and geothermal uses but also of insulation.

Conclusion

Heating systems in Spain underwent few changes in the XIX century. This was not due to the absence of cold weather in Spain but to the impoverished state of the country. Concerns about hygiene in connection with heating and ventilation in public buildings such us hospitals, where matters of hygiene would be self evident, were not addressed. However, new systems of heating began to be introduced into public buildings in the second half of the XIX century.
Knowledge of heating and ventilation in Spain was introduced by means of: 1) the training of future teachers and technicians at the École Centrale in Paris. One notable example was Eduardo Rodriguez who wrote a manual of physics which was used at the Royal Industrial Institute of Madrid, the centre that prepared the first industrial engineers in Spain; and 2) the study of texts written by professors from abroad. The latter way constitutes the subject of this paper.
The École Centrale des Arts et Manufactures, where Peclet taught, was the main centre of knowledge. Another important centre was the Conservatoire des Arts et des Metiers, which was directed by Morin. The influence of the École Centrale spread to Berlin and Zurich and also to Barcelona, in which town it was the engineers rather than architects and physicists who showed most interest.
Echeverría and Rojas wrote reports in support of heating in public buildings in Spain. Rojas took part in the French debate on the importance of innovation whereas Echeverría devoted himself to interpreting and summarizing aspects of Peclet's works.
Finally, another report sought to link ventilation to cooling. Vallhonesta simultaneously presented a device that was a precursor of geothermal energy to provide clean air, and a device that was based on solar panels to extract stale air.
It might be said that in a relatively short period of time industrial engineers in Barcelona were able to discover new techniques, discuss them critically and make improvements. This constitutes the main contribution of these reports which are scarcely comparable because of their size, depth and diffusion. However, they clearly indicate how transfer of knowledge was achieved.
Outside Spain there was a growing awareness that salubrious buildings had a beneficial effect on schools, hospitals, barracks and prisons with the result that governments incorporated systems of heating and ventilation using air, water or steam. By contrast, this was not the case in Spain despite the attempts of engineers to persuade architects to include these systems in their projects.

Bibliografia

ANDUAGA EGAÑA, Aitor (2008), «Lucas Echeverría y Ugarte», *Auñamendi Eusko Entziklopedia*, Bernardo Estornés Lasa Fondoa, http://www.euskomedia.org/aunamendi/36792 (consultat 1/09/2012).

BARCA SALOM, Francesc X. (2010), «Introducción de innovaciones e implicación social. La Real Academia de Ciencias y Artes de Barcelona en el segundo tercio del siglo XIX», *Revista de Humanidades Médicas & Estudios Sociales de la Ciencia y la Tecnologia. Journal of Medical Humanities Social Studies of Science and Technology*, Vol. I, **3** (abril 2010), 1-38 (ISSN 1852-4689) http://www.ea-journal.com/art1.3/Introduccion-de-innovaciones-e-implicacion-social.pdf.

BARCA SALOM, Francesc; LUSA MONFORTE, Guillermo (1995) "Ramón de Manjarrés i de Bofarull (1827-1918): La química agrícola i la professionalització dels enginyers industrials. Dins ROCA, A.; CAMARASA, J.M. *Ciència i Tècnica als Països Catalans: una aproximació biogràfica als darrers 150 anys*. Barcelona: Fundació Catalana per a la Recerca. vol. I, 381-423.

CABALLER, M. Cinta; LLOMBART, José; PELLÓN, Inés (2001), *La Escuela Industrial de Bergara (1851-1861)*, Guipúscoa, Colegio Oficial de Ingenieros Industriales, Gipuzkoako Industri Ingeniaren Elkargo Ofiziala.

CHABANNES, Jean Frederic, Marquès de (1818) *On conducting Air by forced Ventilation, and regulating the Temperature in Dwelling, with a description of the Application of the principles as established in Covent Garden Theatre, and Lloyd's Subscription Rooms; and a short Account of diifferent Patent Apparatus for warming and cooling Air and Liquids. The whole illustrated with Copperpllate Engravings*. Londres: The Patent Calorifere Fumivore Factory.

Diario: *Diario de Barcelona*, 5 de setembre de 1891, p. 10.379.

DONALDSON, Barry; HAGENGAST, Bernard (1994), *Heat & Cold. Mastering the great indoors*, Atlanta, ASHRAE.

DURAN PINEDA, Ricard (2004) "Plantes tintòries i indústria química a la Catalunya del segle XIX: Josep Vallhonesta i Vendrell (1835-1899)" *Recerques* 49 (2004), 53-72.

ECHEVERRÍA UGARTE, Luis (1864), *Consideraciones generales acerca de las aplicaciones de ciertos principios científicos a la teoría y construcción de los aparatos de calefacción*, Memòria de torn llegida a la Reial Acadèmia de Ciències i Arts de Barcelona el 10 de març de 1864, Arxiu RACAB, 90.10.

FIGUIER, Louis (1867) *Les merveilles de la science ou description populaire des inventions modernes.* París : Libraire Furne Jouvet et Cie, éditeurs.

GALLO, Emanuelle; THOMINE, Alice (2004), «Chauffage et ventilation». A: BELHOSTE, Jean-François, *Le Paris des centraliens, bâtisseurs et entrepreneurs*, Paris, Action Artistique de la Ville de Paris, 199-201.

GALLO, Emmanuelle (2003), *Ventilating and Heating Lariboisière Hospital, a Scientific Debate in Paris 1848-1878*, pòster de la 3ème conférence internationale pour l'histoire des hôpitaux, *Form+Function, the Hospital*, McGill University, Montréal, 19-21 juin.

GALLO, Emmanuelle (2006a), «La réception des nouveaux modes de chauffage domestique en France au XIXe siècle», *L'architecture: la réception immédiate et la réception différée. L'œuvre jugée, l'édifice habité, le monument célébré*, sous la direction de Gérard Monnier, Publications de la Sorbonne, 37-51 http://www.emmanuellegallo.net/livre.html (consultat 9/08/2012).

GALLO, Emmanuelle (2006b), «Jean Simon Bonnemain (1743-1830) and the Origins of Hot Water Central Heating» [1043-1060], *2nd International Congress on*

Construction History, Queens' College, Cambridge, UK, 29th March-2nd April, edited by the Construction History Society, http://www.emmanuellegallo.net/livre.html (consultat 9/08/2012).
GALLO, Emmanuelle (2006c), *Modernité technique et valeurs d'usage: le chauffage des bâtiments d'habitation en France*, Thése doctorale, Paris, Université París I Panthéon Sorbonne.
GALLO, Emmanuelle (2008), «Les ouvrages techniques sur le chauffage des bâtiments en France; des inventeurs aux ingénieurs», *La construction savante, les avatars de la littérature techniques*, Centre d'Histoire des Techniques et de l'Environnement (CNAM-EHESS) et l'Institut d'Histoire de l'Art (INHA), París, Picard, 347-355.
GALLO Emmanuelle (2010), «La Contribution du Marquis de Chabannes (1762-1836) à l'innovation en matière de construction de chauffage et d'urbanisme». A: CARVAIS, Robert; GUILLERME, André; NÈGRE, Valérie, SAKAROVITCH, Joel, *Édifice & Artifice. Histoires constructives*, París, Picard, 1.117-1.126.
GARRISSON, F. H., (1927), «The history of heating, ventilation and lighting», *The New York Academy of Medicine*, Vol. III, **2**, February, 57-67 http://www.emmanuellegallo.net/livre.html (consultat 9/09/2012).
GAUGER, Nicolas (1714) *Le Mechanique du Feu ou l'art d'en augmenter les effets, et d'en diminuer la dépense contenant le traité de nouvelles cheminées qui échauffent plus que les cheminées ordinaires, 6 qui ne sont point sujettes à fumer,& c.* Cosmopoli.
JOLY, V. CH. (1872) *Traité pratique du chauffage, de la ventilation et de la distribution des eaus dans les habitations particulières.* París: Librairie Polytechnique J. Baudry, livraire-editeur.
LUSA, Guillermo (1999), *¡Todos a Madrid! La Escuela General Preparatoria de Ingenieros y Arquitectos (1886-1892)*, Barcelona, Documentos de la Escuela de Ingenieros Industriales, núm. 9.
MORIN, Arthur (1863), *Études sur la ventilation*, Vol. I, i II, París, Librairie de L. Hachette et Cie.
Nómina del personal académico (1913-1914), Real Academia de Ciencias y Artes, Barcelona, Sobs, de López Robert y Cª.
Nómina del personal académico (1914-1915), Real Academia de Ciencias y Artes, Barcelona, Sobs, de López Robert y Cª.
O'CONNOR J. J.; ROBERTSON, E. F. (2008), «Arthur Jules Morin», http://www-history.mcs.st-and.ac.uk/Biographies/Morin.html (consultat 8/10/2012).
PÉCLET, E. (1860), *Traité de la chaleur considérée dans ses applications*, París, Librairie de Victor Masson, vol. II.
PÉCLET, E. (1878), *Traité de la chaleur considérée dans ses applications*, París, G. Masson, éditeur, vol. III.
PÉCLET, Eugène (1843), *Traité de la chaleur considérée dans ses applications*, París, Librairie de L. Hachette, vol. I, 2a. ed.
POHL VALERO, Stefan (2006) "La termodinamica comoelemento legitimador dela física teórica y aplicada en la España de la segunda mitad del siglo XIX". *Quaderns d'Història de l'Enginyeria.* Vol VII, 73-114.
REID, David Boswell (1844) *Illustrations of the theory and practice of ventilation with remarks on warming, exclusive lightinng, and the communication of sound.* London: Longman, Brown, Green, & Longmans Paternoster-row.
Revista: "Crónica de la Asociación" *Revista Tecnológico-Industrial*, núm.1, january 1880. Barcelona: Establecimiento tipográfico de Damian Vilarnau, 1882.

RODRÍGUEZ, Eduardo (1858) *Manual de Física General y Aplicada a la agricultura y a la industria.* Madrid: Imprenta, fundición y librería de Don Eusebio Aguado.

ROJAS, Francisco de P. (1868) *Calentamiento y ventilación de edificios*. Memoria premiada por la Real Academia de Ciencias Exactas, Físicas y Naturales en el concurso público de 1867. Madrid: Imprenta de la viuda de Aguado e hijo.

SERRAT Y BONASTRE, José (1909), «Necrológica de D. Francisco de Paula Rojas», *Revista Tecnológico-Industrial*, **4**, 160-161.

The Gardener's: "Chabannes's Pamphlets on heating by hot Water". *The Gardener's Magazine*, vol, IV, 1828. Londres: Longman, Rees, Orme, Brown and Green

TREDGOLD, Thomas (1825), *Principes de l'art de chauffer et d'aérer les édifices publics, les maisons d'habitations, les manufactures, les hôpitaux, les serres, etc., et de construire les foyers, les chaudières, les appareils pour la vapeur, les grilles, les étuves, démontrés par le calcul et appliqués a la pratique; avec des remarques sur ma nature de la chaleur, er de la lumière, et plusieurs tables utiles dans la pratique*, traduït de l'anglés per T. Duverne, París, Bachelier (Successeurs de Mme Ve. Courcier).

VALLHONESTA, José (1872) *Nuevo sistema de ventilación para mantener frescos en el verano los edificios públicos y particulares.* Madrid: Carlos Bailly-Bailliere.

VICUÑA, Gumersindo (1874), «Calefacción y ventilación en edificios», *Revista Europea*, **30** (20 de septiembre), 361-371